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Mitigation of Switching Losses with SHE Modulation Strategy in Grid Interfaced PV Inverters

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ABSTRACT

Interfacing of multimegawatt photovoltaic inverters with grid is getting a greater attention in recent. It is always a challenging task for the engineers as there are certain priorities to be taken while interfacing PV cells to grid without which there will be an unsatisfactory operation of the system. However for high power and medium voltage grid inverters the priorities like switching losses, satisfaction of grid codes and IEEE and IEC standards are to be strictly considered. Reduction of switching losses is the active area of research. In order to meet such requirements we are using the conventional modulation strategy like SHE (selective harmonic elimination). This paper focus on the reduction of switching losses with the help of new implementation technique for SHE that uses third harmonics to have the switching angles over 90^{o} instead in a narrow range by which modulation index is also increased. In order to have the potential superiority of SHE over carrier based or space-vector pulsewidth modulation, this SHE strategy can allow the grid connected inverters to operate using a switching frequency less than 1KHz while it is still able to provide satisfactory operation like simplicity in operation, independent control of active and reactive powers which is not possible in other cases. To validate potential benefits of SHE, it is compared with THI PWM which is controlled with a operating frequency of 2KHz.

Index Terms—Grid-connected PV inverters, pulsewidth modulations (PWMs), selective harmonic elimination (SHE), switching losses, THI PWM (Third harmonic injection pwm)

1. INTRODUCTION

The effectiveness and efficient usage of generated power can be done by interfacing the PV cells with the grid. However, the technical aspects both from the utility power system grid side and the PV system side need to be satisfactory to ensure the safety of the PV installer and the reliability of the utility grid[1][2]. Clarifying the technical requirements for grid interconnection and solving the problems such as islanding detection, harmonic distortion requirements, switching losses and electromagnetic interference are therefore very important issues for widespread application of PV systems. Grid interconnection of PV systems is accomplished through the inverter, which convert dc power generated from PV modules to ac power used for ordinary power supply to electric equipments. Inverter system is therefore very important for grid connected PV systems.

The developments of flexible ac transmission system devices, medium voltage drives, and different types of distributed generations, have provided great opportunities for the implementations of medium- and high-power inverters. In these applications, the frequency of the pulse-width modulation (PWM) is often limited by switching losses and electromagnetic interferences caused by high dv/dt [3]. Thus, to overcome these problems, selective harmonic elimination (SHE)-based optimal pulse width modulation (OPWM) are often utilized in both two level inverters and multilevel inverters to reduce the switching frequency and the total harmonic distortion. Most gird connected PV systems are not apt for the high power due to the usage of higher switching frequency (high switching losses and voltage stress).Almost of the studies use sinusoidal or space-vector pulsewidth modulation to have control over the inverters. The use of sinusoidal strategy doesn't fully utilize dc link voltage, which lowers power density. SVPWM increases semiconductor utilization, dc link voltage and power density, but have difficulties while operating in medium voltage distribution systems where ac faults and unbalance operations are very high. Hence the need for the use of conventional strategy SHE is preferred. Selective harmonic elimination pulse-width modulation (SHE-PWM) has been mainly developed for two- and three-level converters in order to achieve lower total harmonic distortion (THD) in the voltage output waveform.

2. PULSEWIDTH MODULATION FOR GRID-CONNECTED INVERTERS

Many applications such as industrial heating, lighting control and speed control of induction motors require variable ac voltage. Generally triacs or anti parallel connected thyristors are used as power converters in such systems. These converters which are simple ,reliable and cost effective however suffer from various drawbacks such as increased harmonic content and poor power factor especially at lower output voltages[4][5].

The method of giving fixed dc input voltage to the inverter and obtaining a controlled ac output voltage by adjusting the on-off periods of the inverter components is termed as "pulse width modulation"(PWM).The width of the pulse is, however, modulated to obtain inverter output voltage and to reduce its harmonic content.

For a multilevel inverter, switching angles at fundamental frequency are obtained by solving the selective harmonic elimination equations[6] in such a way that the fundamental voltage is obtained as desired and certain lower order harmonics are eliminated. As these equations are nonlinear transcendental in nature, there may exist simple, multiple or even no solutions for a particular modulation index. This paper uses Newton-Raphson method for solving the transcendental equations which produce possible solutions with any random initial guess and for any number of levels of multilevel inverter. Among multiple solution sets obtained, the solutions which produce least THD in the output voltage is chosen [7][8]. As compared with the single set of solution, the decrease in the THD can be up to 3% in case of multiple solution sets.

3. SELECTIVE HARMONIC ELIMINATION PWM TECHNIQUE

The fig.1 (a) and 1 (b) shows output voltage of two level converters relative to supply midpoint which is normalized. When SHE is employed for controlling the inverter with three notches for fundamental voltage adjustment and elimination of fifth and seventh harmonics all the switching angles in Fig 1(a) can be seen in between 0 and 60^0 (solution1) as shown in Fig. 1(c) (solid line). The modulation index which can attain through this is 1.1884. This modulation index is possible by solving optimization problem [9]. The switching angles will be $\alpha_1 < \alpha_2$, $\alpha_2 < \alpha_3$, $\alpha_3 < –$. The arrangement in fig. 1 (b) is for solution2 and produces the switching angles distributed over 90^0 with $\alpha_2 < \alpha_3$ located between 60^0 and 90^0. The modulation index for solution2 is 1.16 which is lower than solution1.In addition it can be observed that solution2 produces a fundamental voltage which is 180^0 out of phase to that of solution1. For the same fundamental voltage this can be observed in Fig.1 (b) as seen most of first cycle of the wave.

This is very much critical in the SHE implementation. For increasing the modulation index for solution2 we are injecting 3^{rd} harmonic content. When a fourth angle is added to 3^{rd} harmonic, the maximum modulation index using solution1 remains at 1.1884 shown in fig.1 (f).

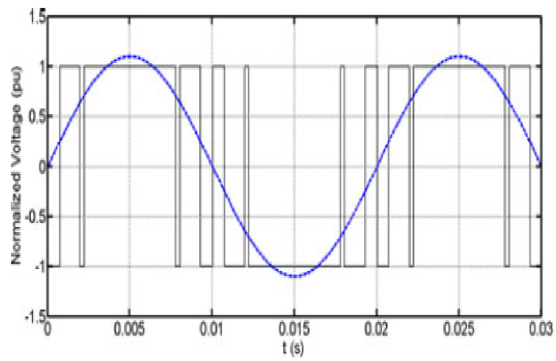

Fig. 1(a): phase voltage when 5^{th} and 7th harmonics are eliminated

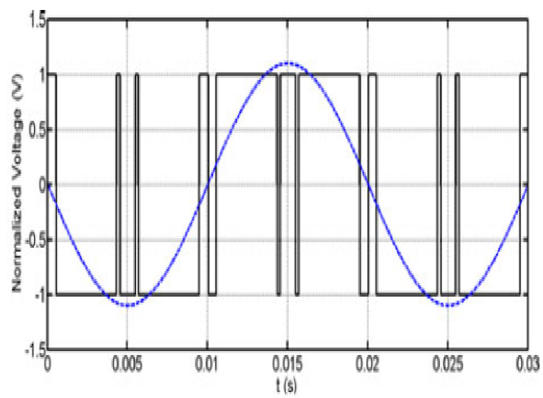

Fig.1 (b): phase voltage when 5^{th} and 7^{th} harmonics are eliminated

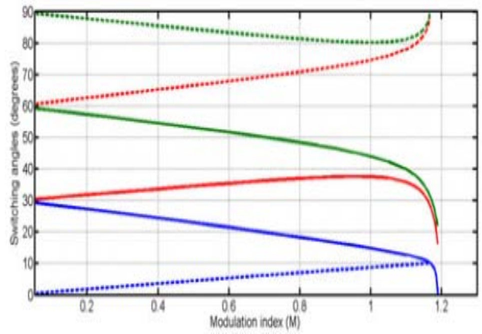

Fig.1(c): switching trajectories for solution 1 and 2 (solid line for solution1, dotted for 2)

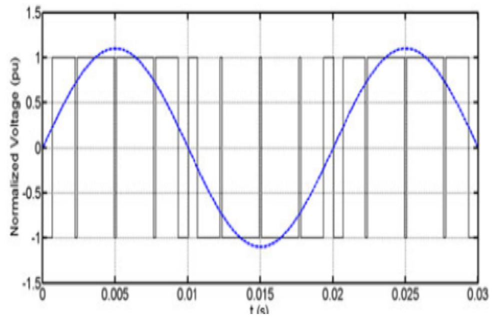

Fig.1 (d): phase voltage when 5th and 7th harmonics removed and 3rd harmonic $M_3/5$

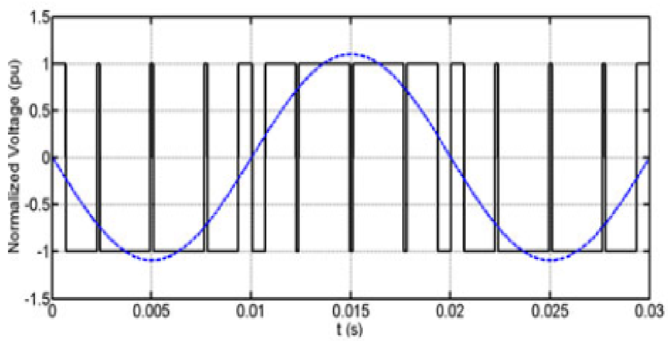

Fig. 1(e): voltage when 5th and 7thharmonics eliminated and 3rd harmonic is $M_3/5$

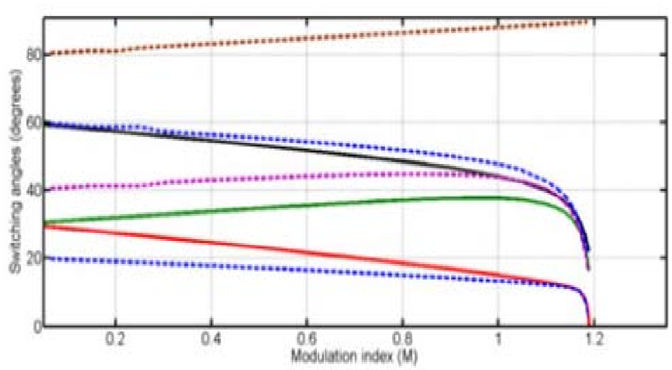

Fig.1 (f): switching trajectories with and without 3rd harmonic for solution1

4. THIRD HARMONIC INJECTION PWM

Fig.2. shows THI natural sampling implementation ,with magnitude of third harmonic equal to 1/6 the fundamental voltage [10]. In this the THI is implemented based on regular sampling with 2KHz switching frequency.

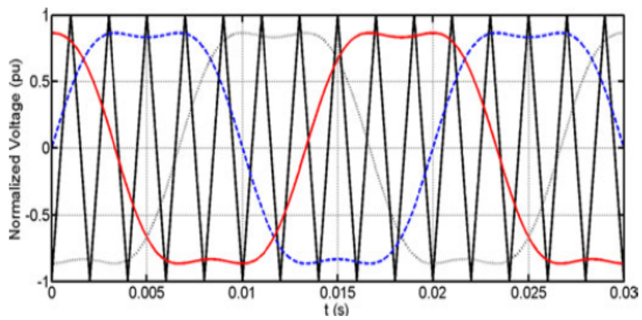

Fig. 2. Implementaion of carrier basedTHIPWM

5. SIMULATION RESULTS AND DISCUSSION

This section deals with the results and their discussion after simulation. For the better validation of Selective Harmonic Elimination technique the results of the both i.e.,grid connected PV inverter with SHE and THI PWM are compared. The simulation parameters of a multimegawatt PV inverter are to be given to each block and are to simulated to get the results. The simulation parameters of PV inverter are tabulated in table 1.

Table. 1. Simulation parameters of a multimegawatt PV inverter

PARAMETERS		VALUES
Converter power rating		25
DC link voltage		20
AC voltage (line-to-line in KV)		11
Active power capability (MW)		20
Reactive power capability in MVAR		15
Grid frequency (KHz)		50
Switching frequency	THI-PWM	2
	SHE	0.95
Current control proportional gain K_p	THI-PWM	70
	SHE	220

Current control integral gain, K_i	THI-PWM	3000
	SHE	5000

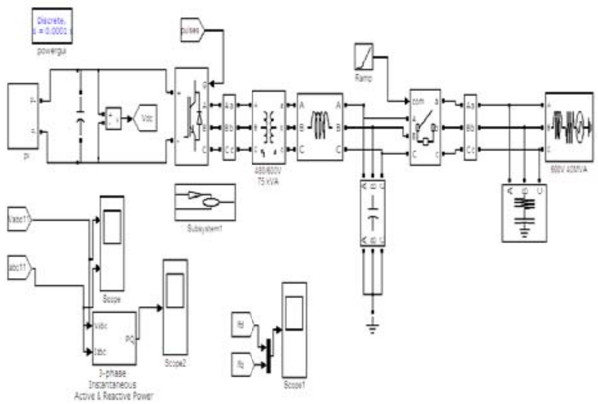

Fig .3 (a): Simulation block for SHE PWM implementation for grid interconnected PV system

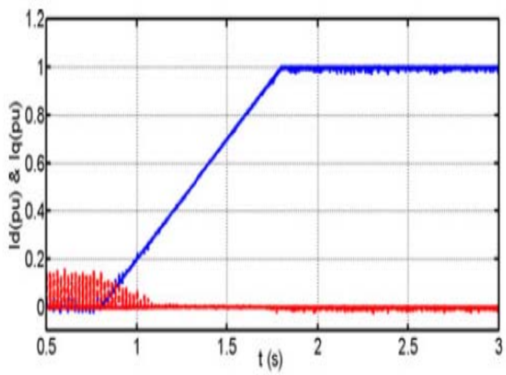

Fig. 3(b): variation of active current,for inverter at full load

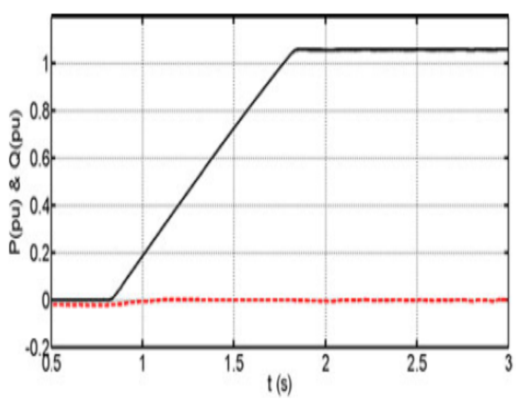

Fig. 3(c): Active and reactive power PV inverter with the grid

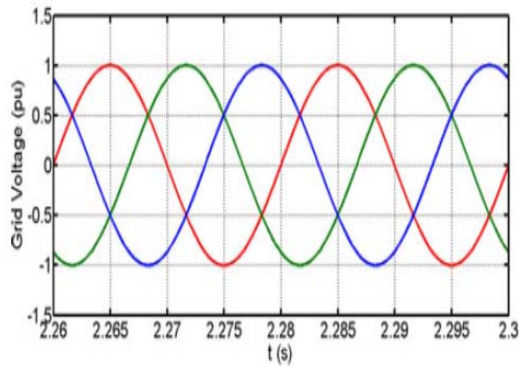

Fig.3(d): Normalized grid voltage

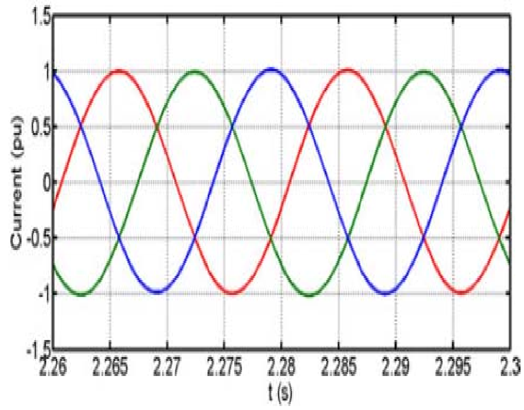

Fig.3(e): Normalized current

The fig. 3. (b) and 3.(c) depicts the variation of active current and active and reactive power of a grid connected PV system. When the system is controlled with the help of SHE technique with a switching frequncy of 1KHz the normalized grid output voltage and current can be seen in fig. 3.(d) and3. (e) respectively.

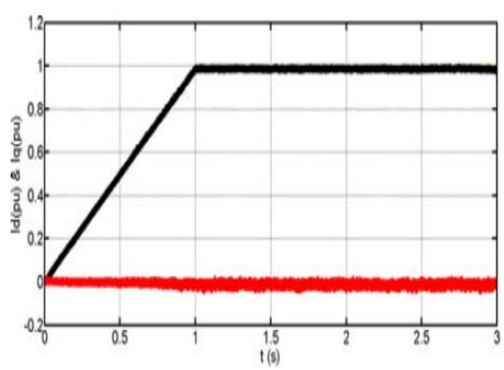

Fig. 4(a): Variation of active current when PV inverter operates at full load

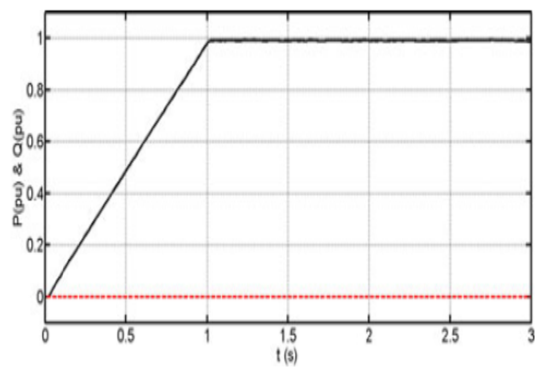

Fig. 4(b): Active and reactive power PV inverter exchanges with the grid

The fig. 4. (a) and 4. (b) shows the variation of active current and active and reactive power of a grid interfaced PV inverter controlled with THI PWM technique with switching frequency of 2KHz. Fig.4.(c) and 4(d) shows the normalized grid voltage and currents.

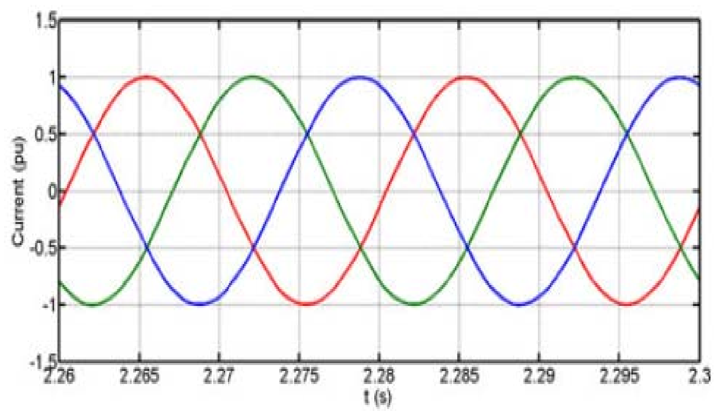

Fig. 4(d): Normalized grid voltage

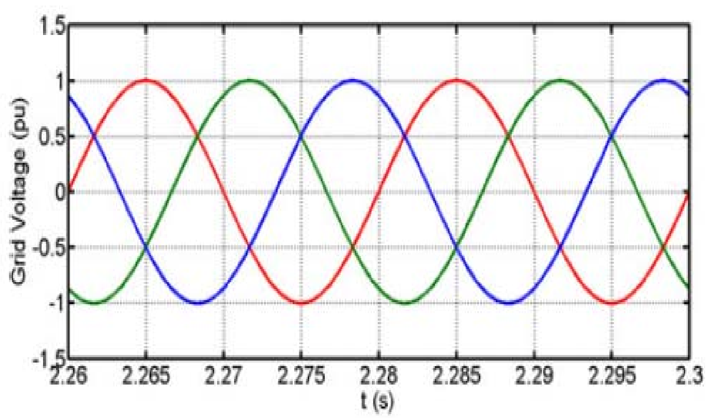

Fig. 4(e): Normalized output current

The results show that SHE can be used in the place of carrier based PWM strategies which are used to control grid connected PV inverter, and maintain all the controlling features achieved by carrier based strategies. The results are obtained when the active power current component I_d is varied from 0 to 1.0 p.u. (25 MVA and 11 KV based). Note that SHE produces the similar performance characteristics that of a THI PWM at approximately half the switching frequency, including ac voltage, system dynamics and current waveform quality [11] [12]. For further illustration of potential gains the switching losses with THI PWM and SHE modulation strategies for a 25 MVA PV inverter are tabulated in table 2.

Table 2.Summary of switching losses with THI PWM and SHE modulation strategies for a 25 MVA PV inverter

Operating condition	**P=20MW at 0.8 power factor lagging**	**Q=15 MVAr at zero power factor**	**20 MW at unity power factor**
SHE	190.6 KW	190.2 KW	88.7 KW
THI-PWM	401.2 KW	400.4 KW	401.2 KW

7. CONCLUSION

This paper enquired the suitability of SHE, which is very much important in drive applications of machine, applied to high power and medium voltage grid connected inverters used as interfacing units for large scale integration of renewable energy sources. It has also demonstrated that it won't violate any functionalities of grid connected inverters i.e., it has the same functionalities of grid connected inverters operating with carrier based PWM strategies. In addition to traditional SHE with the adjustment of third harmonic magnitude, a universal solution for elimination of harmonics equations are solved such that the switching angles are spread over 90^0. This extraordinary feature is extensively used in practical realization of SHE at high modulation indices when more number of harmonics are getting eliminated.

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